CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from United States Provisional Patent Application No. 60/044,898, which is incorporated herein by reference in its entirety and is a continuation in part of United States Patent Application 09/527,552 filed March 17, 2000 entitled "Process and Apparatus for Preventing Oxidation of Metal" by Lewis.

FIELD OF THE INVENTION

The present invention relates to a process and apparatus for phase compensated prevention of oxidation of metal objects in an oxidizing environment. An oxidizing environment is characterized by the presence of at least one chemical, the atoms of which in that environment, are capable of being reduced by acquiring at least one electron from the atoms of the metal. In "donating" an electron, the metal becomes oxidized.

BACKGROUND OF THE INVENTION

In an oxidizing environment, there are substances that under suitable conditions, take up electrons and become reduced. These electrons come from the atoms of metal objects exposed to the oxidizing environment, which ends up being oxidized. As the process of oxidation continues, a metal object becomes degraded to the point that it can no longer be used for its intended purpose.

On land, oxidation is prevalent in, among other things, bridges and vehicles, when

they are exposed to salt that is spread on roads to prevent the formation of ice in cold climates. The salt melts the snow and ice and, in so doing, forms an aqueous salt solution. The iron or steel in the bridges or vehicles, when exposed to the salt solution, is readily oxidized. The first visible sign of oxidation is the appearance of rust on the surface of the metal object. Continued oxidation leads to the weakening of the structural integrity of metal objects. If the oxidation is allowed to continue, the metal object rusts through and eventually disintegrates or, in the case of the metal in bridges, becomes too weak to sustain the load to which it is subjected. The situation has become worse in recent years with increased concentrations of pollutants and the demand for lighter, more fuel efficient vehicles requiring thinner sheet metal and the abandonment of mainframe construction.

The same aqueous salt solution is also the cause of corrosion in a marine environment and is responsible for the oxidation of hulls of ships, offshore pipelines, and drilling and production platforms used by the oil industry.

Early methods of corrosion prevention relied on applying a protective coating, for example of paint, to the metal object. This prevents the metal from coming in contact with the oxidizing environment and thereby prevents corrosion. Over a long time, however, the protective coating wears off and the process of oxidation of the metal could begin. The only way to prevent oxidation from starting is to reapply the coating. This can be an expensive process in the best of circumstances: it is a lot easier to thoroughly coat the parts of an automobile in a factory, before assembly, than to reapply the coating

on an assembled automobile. In other circumstances, e.g., on an offshore pipeline, the process of reapplying a coating is impossible.

Other methods of prevention of oxidation include cathodic protection systems. In these, the metal object to be protected is made the cathode of an electrical circuit. The metal object to be protected and an anode is connected to a source of electrical energy, the electrical circuit being completed from the anode to the cathode through the aqueous solution. The flow of electrons provides the necessary source of electrons to the substances in the aqueous solution that normally cause oxidation, thereby reducing the "donation" of electrons coming from the atoms of the protected metal (cathode).

The invention of *Byrne* (U.S. Patent 3,242,064) teaches a cathodic protection system in which pulses of direct current (DC) are supplied to the metal surface to be protected, such as the hull of a ship. The duty cycle of the pulses is changed in response to varying conditions of the water surrounding the hull of the ship. The invention of *Kipps* (U.S. Patent 3,692,650) discloses a cathodic protection system applicable to well casings and pipelines buried in conductive soils, the inner surfaces of tanks that contain corrosive substances and submerged portions of structures. The system uses a short pulsed DC voltage and a continuous direct current.

The cathodic protection systems of prior art are not completely effective even for objects or structures immersed in a conductive medium such as sea water. The reason for this is that due to local variations in the shape of the structure being protected and to

concentrations of the oxidizing substances in the aqueous environment, local "hot spots" of corrosion develop that are not adequately protected and, eventually, cause a breakdown of the structure. Cathodic protection systems are of little use in protecting metal objects that are not at least partially submerged in a conductive medium, such as sea water or conductive soil. As a result, metal girders of bridges and the body of automobiles are not protected by these cathodic systems.

Cowatch (U.S. Patent 4,767,512) teaches a method aimed at preventing corrosion of objects that are not submerged in a conductive medium. An electric current is impressed into the metal object by treating the metal object as the negative plate of a capacitor. This is achieved by a capacitive coupling between the metal object and a means for providing pulses of direct current. The metal object to be protected and the means for providing pulses of direct current have a common ground. In a preferred embodiment of the invention, *Cowatch* discloses a device in which a DC voltage of 5,000 to 6,000 volts is applied to the positive plate of a capacitor separated from the metal object by a dielectric, and small, high frequency (1 kilohertz) pulses of DC voltage are superimposed on the steady DC voltage. *Cowatch* also refers to a puncture voltage of the dielectric material as about 10 kV.

Because of the safety hazards of having the high voltage applied at a place that exposes humans and animals to possible contact with the metal object or any other part of the capacitive coupling, *Cowatch* requires limitations on the maximum energy output of the invention.

The invention of *Cowatch* discloses a two-stage device for obtaining the pulsed DC voltage. The first stage provides outputs of a higher voltage AC and a lower voltage AC. In the second stage, the two AC voltages are rectified to give a high voltage DC with a superimposed DC pulse. The invention uses at least two transformers, one of which may be a push/pull saturated core transformer. Because of the use of transformers, the energy losses associated with the invention are high. Based on the disclosed values in the invention, the efficiency can be very low (less than 10%). The high heat dissipation may require a method of dissipating the heat. In addition, the invention provides a separate means for shutting off the device during prolonged periods of nonuse to avoid discharging the battery.

A somewhat related problem that affects submerged structures is caused by the growth of organisms. Mussels, for example, are a serious problem with municipal water supply systems and power plants. Because of their prolific growth, they clog the water intakes required for the proper operation of the water supply system or the power plant, causing a reduction in the flow of water. Expensive cleaning operations have to be carried out periodically. Barnacles and other organisms are well known for fouling the hulls of ships and other submerged parts of structures. Conventional means of dealing with this include the use of antifouling paints and thorough cleaning at regular intervals. The paints may have undesirable environmental effects while the cleaning is an expensive process, requiring that the ship be taken out of commission while the cleaning is done. Neither of these is effective in the long run.

It is a goal of the present invention to provide corrosion protection to metal objects even when the object to be protected is not immersed in an electrolyte. It is a further object of the present invention to accomplish this without exposing humans or animals to the risk of high voltages. In addition, the device should also be energy efficient, thereby reducing the drain on the power source and should not require any special means for heat dissipation. It also should, as part of the circuitry, have a battery voltage monitor that shuts off the pulse amplifier if the battery voltage drops below a predetermined threshold, thus conserving battery power. This is particularly useful because cold weather conditions under which corrosion is more likely due exposure to salt used to melt ice on roadways, also imposes greater demands on a battery for starting a vehicle. In addition to cold weather, high temperatures and humidity also lead to increased corrosion simultaneously with increased demands on battery power for starting a vehicle. It is also a goal of the present invention to inhibit the growth of organisms on submerged structures. Finally, it is also a goal of the present invention to protect the circuitry from damage if the apparatus is inadvertently connected to the battery with reversed polarity.

SUMMARY OF THE INVENTION

The present invention overcomes the problems of prior art and effectively prevents the oxidation of metal objects by capacitive coupling a fastener attached to a metal object to a source and passing pulses of direct current at a low voltage from the

source through a capacitor to the fastener and thus through the metal object. The metal object is attached to the negative plate of the capacitor. The apparatus used for providing the pulses of direct current is connected to the positive plate of the capacitor on one side, and to a ground, to which the fastener and metal object is also connected, on the other side. The apparatus is directly attached to the metal object with a machine or sheet metal screw and the capacitor is contained in a separate housing.

In an alternative embodiment, a pad is used to create the positive plate of a capacitor which attaches to the metal object. The metal object acts as the negative plate. A dielectric material is interposed between the positive plate of the capacitor and the metal object. The paint on the metal object, if present, acts as an additional layer of dielectric material.

The pulses of direct current are produced by circuitry that includes a microprocessor, a reverse voltage protector, a pulse amplifier, a battery voltage monitor, a power indicator and a power conditioner to deliver pulses of direct current at a low voltage to the positive plate of the capacitor. Diodes, transistors, resistors, inductors and capacitors are used in the electronic circuit components; the circuitry does not include any transformers, thereby eliminating a major source of power loss.

In normal operation, when the exposed surface of the metal object is dry, the effective area of the capacitor is limited to the positive plate of the capacitor. When the surface of the metal is wet, or has a thin film of moisture on it, the presence of chemicals

that have a sufficient reduction potential to acquire electrons from the metal increases the likelihood of oxidation and corrosion of the metal. These same chemicals that can cause corrosion also make the water or moisture film on the metal object electrically conductive; because of this, the effective area of the capacitor may increase from just the metal plate to the area covered by the electrically conductive water or film of moisture. The result of this increased capacitance is an increase in the current flowing through the circuit into the metal. Thus, the present invention is self-regulating in that the greater the possibility of corrosion, the greater the amount of protective current delivered to the metal.

The present invention is also effective, with little modification in inhibiting the growth of organisms, such as mussels and barnacles, on submerged structures.

The present invention provides two or more electrodes for attachment to large metallic structures, such as water storage tanks and metallic storage sheds or large vehicles. A first and second electrode are attached to metallic structure or vehicle being treated so that the effects of the invention are applied simultaneously at two or more points. Each of the electrodes apply a time varying electrical waveform to the object being treated. A first electrode on a short cable is applied at one point on the object and a second electrode attached to a longer cable is applied at a second point on the object being treated. A phase sensor is used to adjust the signal so that the impedance difference of the long cable and short cable does not affect the phase synchronous relationship of the two applied signals. That is, the impedance of the first and second cable is determined and the signal applied to each cable is adjusted so that the signals at

the distance end of each cable are phase synchronous or are in phase. A high voltage protection circuit is provided to protect the present invention from damage from a high voltage spike or surge. A variable speed blinking led is provided to indicate battery power levels of full, marginal and low.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A-B is a circuit diagram of the prior art of *Cowatch*;

FIG. 2 is a schematic diagram of the apparatus of the present invention;

FIG. 3A-C is a circuit diagram of the preferred embodiment of the present invention;

FIG. 4 is an alternative embodiment of the present invention; and

FIG. 5 is a preferred embodiment of the preferred phase compensation present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is best understood by first referring to prior art methods of preventing oxidation of metal by capacitive coupling. The upper portion of **Fig.** 1 shows the circuit diagram of a push/pull saturated core transformer used in the invention of *Cowatch*. Terminal **1** is connected to the positive side of the electrical system of a vehicle and terminal **2** is connected to the negative side of the electrical system of the vehicle. The output of the transformer **81** has three taps, **21, 22** and **23.** The tap **21** provides the system ground, **22** provides 12 volts AC and **23** provides 400 volts AC. The

output from the first stage is fed to the second stage, a rectifier pulsator, the circuit diagram of which is shown in the bottom portion of **Figure 1**. The 400 volt AC from **23** is fed to **50**, the 12 volt AC from **22** is connected to **51** while the ground **21** is connected to **52.** The output of the rectifier pulsator, between **77** and **73**, is a 400 volts DC with 12 volts pulses superimposed on the 400 volts DC.

The prior art invention delivers a high voltage DC with low voltage pulses superimposed on the high voltage DC to a positive plate of a capacitor connected between **73** and **77.** The positive plate of the capacitor is separated from and coupled to the grounded metal object by means of a capacitive pad.

Figure 2 is a functional block diagram illustrating the operation of the apparatus of the present invention. The battery **101** is the source of DC power for the invention. One terminal of the battery is connected to the ground, **103.** The positive terminal of the battery is connected to the Reverse Voltage Protector, **105.** The reverse voltage protector prevents application of reverse battery voltage from being inadvertently applied to the other circuitry and damaging the components.

The Power Conditioner, **107**, converts the battery voltage to the proper voltage needed by the microprocessor, **111.** In the preferred embodiment, the voltage needed by the microprocessor is 5.1 volts DC. The battery voltage monitor, **109**, compares the battery voltage with a reference voltage (12 volts DC in the preferred embodiment). If the battery voltage is above the reference voltage, then the microprocessor **111**, activates

the pulse amplifier, **113**, and the power indicator, **115**. When the pulse amplifier is activated by a pulse signal having a positive output of the microprocessor, an amplified pulse signal having a positive output is generated by the pulse amplifier and conveyed to the pad, **117.** The pad, **117**, is capacitive coupled to the metal object being protected, **119.** When the power indicator **113** is activated, a power LED in the power indicator is turned on, serving as an indicator that the pulse amplifier has been activated. The use of the battery voltage monitor **109** prevents drain on the battery if the battery voltage is too low.

When the present invention is used to protect a metal object, such as the body of an automobile, the pad **117** has a substrate material similar to thin fiber glass and is attached to the object **119** by means of a high dielectric strength silicone adhesive. In the preferred embodiment, the substrate-adhesive combination has a breakdown potential of at least 10 kilovolts. The adhesive is preferably a fast curing one, which will cure sufficiently in 15 minutes to secure the dielectric material to the metal object.

With the broad overview of the invention in **Figure 2**, the details of the device, shown in **Figures 3A- 3C** are easier to understand. The unit is powered from a typical car battery in which the positive terminal of the battery is connected to **133** on a connector panel **131.** The negative terminal of the battery is connected to the body of the car (the "ground") and to **137** on the connector panel **131.** The pad **117** from **Figure 2** is connected to **139** on the connector panel **131** while the metal object being protected, **119** in **Figure 2,** is connected to the ground. The car battery, the pad **117** and the metal object

being protected, **119**, and their connections are not shown in **Figure 3A**.

The reverse voltage protection circuit **105** of **Figure 2** comprises of the diodes **D3** and **D4** in **Figure 3A**. In the preferred embodiment of the invention, **D3** and **D4** are IN4004 diodes. Those who are familiar with the art would recognize that with the configuration of the diodes as shown, the voltage at the point **141** will not be at a negative voltage with respect to the ground even if the battery is connected to the connector board **131** with reversed polarity. This protects the electronic components from damage and is an improvement over prior art.

The power conditioner circuit, **107** in **Figure 2**, is made of resistor **R1**, Zener diode **D1** and capacitor **C1.** These convert the nominal battery voltage of 13.5 volts to the 5.1 volts needed by the microprocessor. In the preferred embodiment, **R1** has a resistance of 330Ω, **C1** has a capacitance of 0.1 μF and **D1** is an IN751 diode. As would be known to those familiar with the art, a Zener diode has a highly stable reference voltage across the diode for a wide range of current through the diode.

Capacitors **C8, C9** and **C10** serve the function of filtering the battery voltage and the reference voltage. In the preferred embodiment, they each have a value of 0.1 μF. **C8** and **C9** could be replaced by a single capacitor with a value of 0.2 μF.

The battery voltage monitor comprises of resistors **R2, R3, R4, R5** and **R6** and capacitors **C4** and **C5.** The voltage is monitored by a comparator in the microprocessor

145. The voltage divider, comprising of resistors **R2** and **R3,** provides a stable reference to the pin **P33** of the microprocessor **145.** In the preferred embodiment, **R2** and **R3** each have a resistance of 100KΩ. Accordingly, with the reference voltage of the Zener diode **D1** of 5.1 volts, the voltage at pin **P33** of the microprocessor would be 2.55 volts. In the preferred embodiment, the microprocessor **145** is a Z86ED4M manufactured by Zilog.

The battery voltage is divided by the resistors **R5** and **R6** and applied to the comparator input pins **P31** and **P32.** In the preferred embodiment, **R5** has a resistance of 180K and **R6** has a resistance of 100KÙ. The comparator in the microprocessor **145** compares the battery voltage divided by **R5** and **R6,** at pins **P31** and **P32,** with the divided reference of 2.55 volts at pin **P33.** Whenever the voltage at pins **P31** and **P32** drops below the reference voltage at pin **P33,** microprocessor senses a low battery voltage and stops sending signals to the pulse amplifier (discussed below). The necessity for connecting pin **P00** to the junction of resistors **R5** and **R6** through resistor **R4** arises because the comparator is responsive only to transitions wherein the voltage at pins **P31** and **P32** drops below the reference voltage at pin **P33.** The pin **P00** is pulsed approximately every one second or so between 0 volts and 5 volts by the microprocessor. When the pin **P00** is at zero volts, then with a resistance of 100KÙ for resistor **R4** in the preferred embodiment, the voltage at pins **P31** and **P32** is below the 2.55 volts reference voltage at pin **P33** when the battery voltage is below 11.96 volts. When the pin **P00** is at 5 volts, the voltage at **P31** and **P32** is above 2.55 volts. By this means, the microprocessor is able to sense a low battery voltage in continuous operation. Capacitors **C4** and **C5** provide AC filtering for these voltages.

Those familiar with the art would recognize that the requirement for cycling pin **P00** between two voltage levels, and the requirement for resistor **R4**, would not be necessary in other microprocessors in which the comparator may be responsive to actual differences between a reference voltage and a battery voltage, rather than to a transition of the battery voltage below the reference voltage.

The use of a microprocessor to generate pulses of DC voltage and the use of a battery voltage monitor to shut down the apparatus when the battery voltage drops below a reference level are improvements over prior art methods. The Power Indicator comprises an LED **D2**, transistor **Q5** and resistors **R7, R8** and **R9.** The transistor **Q5** is driven on by a positive output of the microprocessor at pin **P02.** When the transistor **Q5** is on, the LED **D2** is lit. If the battery voltage is reduced to a nominal 12 V, the microprocessor does not have a positive output at pin **P02** and the LED **D2** is turned off . When the battery voltage rises above a nominal 12 volts, the microprocessor has a positive output on pin **P02** and the LED **D2** is turned on.

In the preferred embodiment, **Q5** is a 2N3904 transistor, **R7** has a resistance of 3.9KΩ, **R8** has a resistance of 1KΩ and **R9** has a resistance of 10KΩ.

When the battery voltage is above the nominal 12 V, the microprocessor also produces an output pulse on pin **P20.** This is sent to the Pulse Amplifier, comprising of resistors **R11 - R16** and transistors **Q1 - Q4.** In the preferred embodiment, **Q1**, **Q3** and

Q5 are 2N3904 transistors, **Q2** and **Q4** are 2N2907 transistors; **R11** has a resistance of 2.7KΩ, **R12** and **R13** each have a resistance of 1KΩ, **R14** and **R15** have resistances of 390Ω, and **R16** has a resistance of 1KΩ. The capacitor **C7** provides AC filtering for the pulse amplifier circuit and, in the preferred embodiment, has a capacitance of 20 μF. The output of the pulse amplifier is applied, through **139** in the connector panel **131**, to the coupling pad **117** that is attached to the car body. The output has a nominal amplitude of 12 volts.

With the complete absence of any transformers in the invention, high efficiency can be readily achieved. This reduces the drain on the battery and is an improvement over prior art. In the preferred embodiment, the signal from pin P20 of the microprocessor comprises of a 5 V, 3.5 ìs wide pulse that occurs at a nominal 11 kHz repetition rate. A range of pulse durations between 1 ìs and 10.0 ìs has been found to be satisfactory. A repetition rate of between 5 kHz and 50 kHz has been found to be acceptable. A pair of important parameters is the rise and fall times of the amplified pulse signal that is applied to the pad **117**. In the preferred embodiment, the rise time and the fall time of each pulse that forms the amplified pulse signal are both less than 200 nanoseconds.

The clock for the microprocessor in the preferred embodiment is the resonant circuit comprising of capacitors **C2** and **C3** and the inductor **L1**. Use of this circuit is more cost effective than a quartz crystal for controlling the microprocessor clock. This is an improvement over prior art. In the preferred embodiment, **C2** and **C3** have a

capacitance of 100 pF while the inductor **L1** has an inductance of 8.2 μH. Those familiar with the art would recognize that other devices or circuits could be used to provide the timing mechanism for the microprocessor.

Turning now to **Figure 4**, an alternative embodiment of the present invention is illustrated which utilizes an internal capacitor **160**, lead **161** and fastener **162** to deliver pulses to the metal object **119**, instead of capacitive pad **117.** In **Figure 4,** the output of pulse amplifier **113** is attached to the positive side of capacitor **160**. The negative side of capacitor **113** is attached to lead **161** which is attached to fastener **162**. The output pulses from pulse amplifier **113** are thus transmitted to metal object **119** via the path formed by capacitor **160**, lead **161** and fastener **162** which is attached to metal object **119**.

Turning now to **Figure 5** a preferred embodiment of the present invention is shown illustrating the phase sensor and adjustment circuitry for system provided two or more electrodes. The present invention provides two or more electrodes for attachment to large metallic structures, such as water storage tanks and metallic storage sheds or large vehicles. A first and second electrode are attached to metallic structure or vehicle being treated so that the effects of the invention are applied simultaneously at two or more points. Each of the electrodes apply a time varying electrical waveform to the object being treated. A first electrode on a short cable is applied at one point on the metal object and a second electrode attached to a longer cable is applied at a second point on the metal object being treated. A phase sensor is used to adjust the signal so that the impedance difference of the long cable and short cable does not affect the phase synchronous relationship of the two applied signals. That is, the phase relationship of the signals

applied to the metal object and complex impedance of the first and second cable is determined and the signal applied to each cable is phase compensated and adjusted so that the signals at the distant end of each cable are phase synchronous or are in phase when applied to the metal object. A high voltage protection circuit is provided to protect the present invention from damage from a high voltage spike or surge. A variable speed blinking led is provided to indicate battery power levels of full, marginal and low.

As shown in **Figure 5**, a first lead **161** and a second lead **166** are driven by pulse amplifier **213**. Pulse amplifier **213** contains phase delay circuitry to adjust for any phase delay due to impedance differences between cable **161** and cable **166** which may be of different lengths and thus exhibit different impedances and phase delays. Different impedance in each cable tends to independently shift the phase of each output signal at the distant end of the cable as applied to the object via fastener **162** or **167**. Thus, the present invention provides phase compensation, that is, phase sensing of each out put signal at the fastener or application point to an object and appropriate phase compensation or delay to bring each output signal into phase synchronization. Thus, the present invention monitors and adjusts the phase of the output signal at each fastener **162** and **167**. Otherwise, the applied signals can be out of phase synchronization and cause the application of the output signals to be less effective. It is more electrically efficient to adjust the phase of each fastener applied signal so that the peak of each fastener signal is coincident with the peak of other fastener signals applied to a metal object. Thus, the present invention insures that each signal at each fastener applied to a metal object is phase synchronous.

The phase of each signal at each fastener can be determined by attaching each fastener **162** and **167** to a phase sensor **170** to determine the phase relationship of each signal at each fastener **162** and **167**, after the signal has passed through the delivery cables **161** and **166** and capacitors **160** and **165**. The microprocessor **111** determines a phase difference and sends a phase delay signal to pulse amplifier **213**, which applies a phase delay signal to pulses sent to each cable so that the signals are in phase synchronization when applied to an object through the fasteners. The phase sensor and pulse amplifier can also sense and adjust for differences in the complex impedance between two applied signals. A similar circuit is used to adjust the phase of applied signals in the embodiment where capacitive coupling is used to apply the signals to an object.

Power indicator **215** comprises a voltage sensing circuit, a flasher and a voltage indication and LED. (I think this is correct?) The power indicator circuit causes the LED to flash at 1/8 second frequency when the supply voltage is twelve volts, at 1/4 second frequency when the supply voltage is less than twelve volts and greater than 11.7 volts, and at ¼ second frequency when the supply voltage is less than 11.7 volts. A surge protection circuit **172** is provided to protect the present invention from high voltages due to regulator failure or other sources of high voltage.

The foregoing is intended to be a description of the preferred embodiment of the invention. Variations of the disclosed embodiment may be easily made and are intended to be within the scope of the invention.